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MODELING THE IMPACT OF ANIMAL FARMING ON WATER QUALITY OF SG SERIN

Rohene A/P Srikaran

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List of Abbreviations

BOD	biochemical oxygen demand
BOD_5	5-day biochemical oxygen demand
CBOD	carbonaceous biochemical oxygen demand
$CBOD_f$	fast carbonaceous biochemical oxygen demand
$CBOD_5$	5-day carbonaceous biochemical oxygen demand
Cu	copper
DO	dissolved oxygen
HW	headwater
ICP-MS	inductively coupled plasma mass spectrometer
INWQS	Interim National Water Quality Standards for Malaysia
Ni	nickel
P	phosphorus
P_{io}	inorganic phosphorus
P_o	organic phosphorus
Pb	lead
QUAL2E	Enhanced Stream Water Quality Model
TMDL	total maximum daily loads
TP	total phosphorus
U.S. EPA	United States Environmental Protection Agency
WQ	water quality
Zn	zinc

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Rohene a/p Srikaran

Resource Chemistry Programme
Faculty of Science and Technology
Universiti Malaysia Sarawak

ABSTRACT

Animal farming has been cited by the Department of Environment as one of the main sources of water quality degradation in Malaysia. Sg Serin, a tributary of Batang Samarahan in Sarawak and which has animal farms such as poultry and pig farms built along it, has been showing degrading water quality. The water quality of the river has been assessed and the impacts of the farm effluents on the river are modeled with QUAL2K. The stream water parameters tested include temperature, pH, dissolved oxygen (DO), 5-day biochemical oxygen demand (BOD_5), inorganic (P_{io}) and organic phosphorus (P_o) as well as heavy metals (Zn, Ni and Pb). DO and BOD_5 levels obtained ranged from 2.24-5.00 mg/L and 1.86-7.99 mg/L respectively while P_{io} and P_o levels ranged from 0.04-4.64 mg/L and 0.45-21.11mg/L respectively. From that range, the lowest DO and the highest BOD_5, P_{io} and P_o were all measured in Sg Pam, the tributary that receives direct discharge from the animal farms. Measured data from the tributaries showed that the tributaries are classified under Class III and IV while Sg Serin itself was under Class II under the Interim National Water Quality Standards for Malaysia. After model calibration and validation, simulation analysis using QUAL2K found that untreated animal wastewater would cause the river to be under Class III while treated wastewater would put the river under Class II. The simulation results concur with the measured observed data which indicates that QUAL2K can be used to successfully predict water quality in Sg Serin.

Keywords: Animal farming, water quality, QUAL2K

ABSTRAK

Menurut Jabatan Alam Sekitar Malaysia, penternakan haiwan merupakan salah satu punca utama berlakunya pencemaran air di Malaysia. Sg Serin merupakan anak sungai Batang Samarahan di Sarawak dan ladang haiwan seperti ladang ayam dan khinzir telah didirikan bersepanjangan sungai tersebut. Sg Serin juga menunjukkan kualiti air yang semakin teruk. Maka, kualiti air Sg Serin serta impak efluen dari ladang haiwan ke atasnya telah dikaji menggunakan model QUAL2K. Parameter yang telah dikaji ialah suhu, pH, oksigen terlarut (DO), permintaan oksigen biokimia (BOD_5), fosforus organik (P_o), fosforus tidak organik (P_{io}) serta logam berat (Zn, Ni dan Pb). Didapati DO dan BOD_5 adalah dalam julat 2.24-5 00 mg/L serta 1.86-7.99 mg/L manakala P_{io} dan P_o adalah dalam julat 0 04-4.64 mg/L dan 0.45-21 11mg/L. Daripada julat-julat tersebut, didapati DO yang terendah serta BOD_5, P_{io} and P_o yang tertinggi adalah dari Sungai Pam, anak sungai yang menerima air kumbahan dari ladang haiwan. Hasil kajian ini turut mendapati bahawa kesemua anak sungai adalah di bawah kelas III manakala Sg Serin adalah di bawah kelas II mengikut Piawai Kualiti Air Kebangsaan Interim Malaysia. Setelah QUAL2K telah disesuaikan dengan data kajian dan disahkan, analisa ramalan kualiti air menggunakan model tersebut telah mendapati bahawa air kumbahan haiwan yang tidak dirawat telah meletakkan Sg Serin di bawah kelas III manakala air kumbahan yang telah dirawat meletakkan sungai tersebut di bawah kelas II. Kedua-dua hasil analisa ini bersetuju dengan hasil kajian kualiti air dan ini menunjukkan bahawa QUAL2K boleh digunakan untuk meramalkan kualiti air di Sg Serin dengan jayanya

Kata kunci: Penternakan haiwan, kualiti air, QUAL2K

1.0 Introduction

Sg Serin is located at 1.267° latitude and 110.45° longitude and is a tributary of the Batang Samarahan River in the Samarahan Basin where the basin covers an area of 1090 km^2. Along the river, land is being used for animal farming, namely poultry and pig farming while there are also agricultural activities further upstream the river from where the animal farms are located. In spite of the growing farming and agricultural practices, Sg Serin has not been modeled before. The only study that has been documented on the river showed that its water quality is being compromised due to pig farming (Ling et al., 2006).

The impacts of animal farming are numerous; it causes elevated nutrient levels, puts the river at risk from eutrophication and it increases biochemical oxygen demand (BOD) while lowering dissolved oxygen (DO) levels. It harms both aquatic life because of the depressed DO levels and gives way only to hardy species, thus altering the river ecosystem. It also subjects the river to blooming microbial populations and pathogens that can potentially spark a disease outbreak among humans.

Since the study conducted by Ling et al. (2006), it is not clear how much the river quality has changed since the introduction of the farm or how much the river can take in waste loads before it is considered polluted. Thus this research aims to assess the river quality of Sg Serin as well as to determine its waste load capacity. This particular model is employed because it has been extensively used with success in assessing waste load capacities of rivers and its equations and applications are well documented (Chaudhury et al., 1998).

The report is thus outlined as follows where a more detailed background on the impacts of animal farming on the environment and modeling are discussed. The methodology employed in carrying out this research is fully described in the materials and methods section while the report concludes with the results, discussion and the conclusion of this research.

2.0 Objectives

The objectives of this study are:

1. To assess the quality of the river based on these basic parameters where in situ analysis include temperature, pH and DO while lab analysis includes 5-day biochemical oxygen demand (BOD_5), inorganic phosphorus (P_{io}), organic phosphorus (P_o) and heavy metals (Ni, Zn and Pb).
2. To calibrate and validate QUAL2K with the field data obtained.
3. To determine the waste load capacity of Sg Serin through QUAL2K simulations.
4. To classify the status of the river according to the Interim National Water Quality Standards for Malaysia.

3.0 Literature Review

3.1 Impacts of animal farming on water quality

3.1.1 Status of livestock industry in Sarawak

The Department of Environment, Malaysia reported in 2006 that pig farming was the third largest source of water pollution in Malaysia after sewage treatment plants and manufacturing industries. Animal farms or more specifically pig farms were responsible for 4.58% of polluted waters across Malaysia (Department of Environment, Malaysia, 2006). The provisional statistics provided by the Department of Veterinary Services showed that poultry and pig farming are the biggest industries in Sarawak in 2006 where both the standing populations combined were at 31,879,305; which is 98% of the total livestock population in the state (Department of Veterinary Services, 2007).

3.1.2 Transport of farm effluents into streams

Animal farm effluents are usually associated with nitrogen, phosphorus, heavy metals and organic compound pollution in water bodies (Wang et al., 2004). The effluents travel to streams in three major ways that is (1) through the direct discharge of animal wastes into streams (2) surface runoff and (3) leaching from soils contaminated with nutrients and heavy metals (Hooda et al., 2000; Stone et al., 1998). Direct discharges occur when animal wastes are directly channeled to streams without proper treatment while surface runoff can occur when animal wastes are either not properly stored or when rainfall carries some animal feed and wastes to the stream.

Ainon et al. (2005) further showed that pig farming practices in Malaysia involved hosing down pigs in an effort to cool the animals, thus further increasing effluent discharge into streams via surface runoffs. Leaching of wastes from the soils occur when excessive nutrients are mobilized to move through the soil and into the waters. Phosphorus mostly reaches streams via runoffs due to their solubility and mobility properties (Sharpley et al., 1997).

3.1.3 Environmental impacts of animal farms

Phosphorus is a key factor in causing eutrophication. The excess nutrient levels spur algal bloom which in turn causes higher decomposition rates when the algae die. The death of algae increases the organic content in streams and their decomposition leads to lower DO levels as they are needed for microbial activity. The lower oxygen levels causes an increase in the BOD in water and by Malaysian standards, any DO level below 5 mg/l will require extensive treatments. Similarly a BOD level above 6 mg/l will require extensive treatment before it is fit to be supplied to homes and industries. Those levels also signify that it is only able to support hardy species in the water and it is unfit for recreation. This can severely affect the ecosystems that the stream supports while reducing the aesthetic, recreational and drinking functions of the stream.

3.1.4 Heavy metal contamination from animal farms

Animal farms have also been found to cause heavy metal contamination namely in Zn, Cu, Cd and Pb (Saed, 2002). A review by Nicholson et al. (2003) showed that animal feed contained background heavy metal concentration and the majority of the heavy metal consumed shows up in the manure. Most animal feed appear only in trace amounts and are only sometimes added as supplementary diets to promote growth in animals (Wang et al., 2004). Zn for instance is used in swine diets to promote growth while other heavy metals such as Cd may be present in animal diets due to the addition of limestone (Nicholson et al., 2003). At any rate, heavy metals are tested as only a trace amount is required to cause toxicity in aquatic life and humans.

3.2 Stream Water Quality Modeling

3.2.1 QUAL2E

Water quality modeling is still in its infancy stages in Malaysia where there is not much research done on this area. The previous studies that has used modeling or QUAL2E to be exact is the case study in Merlimau River, Malacca and Selangor River, Selangor (Mohamed et al., 2004). The Sg Selangor case study involved the use of QUAL2E to build a preliminary database particularly on the flow of the river for better management of the river in the future.

In the Merlimau river case study however, the model was used to determine flow augmentation and waste load capacity of the river where it was found that $0.0025m^3/s$ flow is needed to maintain the river's DO at a bare minimum of 3 mg/l. The study was later followed up in 2007 to show that the river has degraded to Class V from Class III in 2004 (Tengku Yahya & Mohamed, 2008). The study shows that with QUAL2E modeling, the quality of a river can be assessed and tracked over a period of time. Both studies in 2004 and 2007 however are sketchy on the methodology employed in obtaining field data and no statistical analysis was carried out to gauge the reliability of the field data.

QUAL2E has been used all over the globe from the U.S. to Europe and to Asia as can be seen from the numerous studies that have been conducted using the model. Some of the studies conducted using QUAL2E includes the modeling of the Blackstone River (Chaudhury et al., 1998), Yamuna River (Paliwal et al., 2007) , Kali River (Ghosh & Mcbean, 1998) , Passaic River (Melching & Yoon, 1996), Raritan River (Park & Uchrin, 1990), Nakdong River (Park & Lee, 2002) and Sava River (Drolc & Koncan, 1996). The model allows a river's quality to be simulated under different waste load conditions and thus have been used quite extensively in the waste load allocation process in the past two decades. The model has also been used for discharge and permit determinations as well as other conventional evaluations (Chaudhury et al., 1998; Brown & Barnwell, 1987).

QUAL2E requires a converging stream of network of computational elements and reaches with headwaters, waste discharge, water intake points and tributaries joining the main stream to able to simulate waste load allocations more accurately because all the parameters have an impact on the results (Brown & Barnwell, 1987). It can simulate up to 15 constituents which are DO, BOD, temperature, algae as chlorophyll-a, organic nitrogen as nitrogen (N), ammonia as N, nitrite as N, nitrate as N, organic phosphorus, dissolved phosphorus, coliforms, an arbitrary non-conservative constituent, and three conservative constituents (Brown & Barnwell, 1987; Chaudhury et al., 1998; Caviness et al., 2006). The model however is most extensively used for DO, N, phosphorus and algal predictions because it takes into account the full cycle involving the parameters (Chaudhury et al., 1998).

Cox (2003) classifies QUAL2E as an intermediate model as it does not require extensive data requirements such as the MIKE 11 or ISIS model. The benefit of using QUAL2E is that it requires only partial hydraulic data without oversimplifying processes that would render predictions inaccurate and it does not require extensive data for accurate sediment predictions. Other advantages cited are that it can simulate algae as chlorophyll-a. It also includes automatic uncertainty analysis such as the Monte Carlo simulation and its code and theoretical background behind the model are extensively documented as it has been used world-wide in a wide range of water quality modeling exercises (Cox, 2003).

The whole basis of QUAL2E's concept lies on three assumptions made (1) that river networks are well-mixed (2) transport mechanisms are only significant along the major flow of the river and (3) that the stream hydraulic regime is at a steady state (Keller, 2005; Cox, 2003). The steady state equations involved to compute flow characteristics are given as empirical equations where the user can opt to use the functional or geometric representation; thus making it easier to simulate hydraulic properties of a stream (Brown & Barnwell, 1987).

3.2.2 QUAL2K

QUAL2K was built in response to overcome some of the limitations of QUAL2E such as its failure to include CBOD and bottom algae simulation (Chapra et al., 2006). It is still similar to QUAL2E in terms of it being one dimensional, employing steady state hydraulics, allowing dendritic networks, having diel heat budget and diel water quality kinetics in addition to heat and mass inputs. It differs however from QUAL2E on the operating platform; model segmentation; additional simulations and additional hydraulic data (Chapra et al., 2006).

QUAL2K runs on the newer Windows operating platforms where Excel is the graphical interface which makes it more easily applicable on current computers as current computer models are mostly run on a Windows XP platform and above. QUAL2K's additional simulations include CBOD speciation; pH; alkalinity; total inorganic carbon that accounts for better representations of the processes in a stream while the additional hydraulic data includes weirs. In QUAL2K also, the model allows different lengths in elements to be simulated unlike QUAL2E which needed the computational elements in reaches to be of equal length (Chapra et al., 2006).

Research on stream monitoring using QUAL2K is less extensive than research studies using QUAL2E. In fact, the QUAL2K model is still under peer review and has yet to be approved by U.S. EPA (Chapra et al., 2006). The few studies that have been conducted using QUAL2K are the case study in Nakdong River, Korea and Bagmati River, Nepal. QUAL2K was used in the Korean river together with QUAL2E to validate certain modifications on computational structure and the addition of new constituent interactions such as conversion of algal death to BOD and denitrification.

The study concluded that both models were in good coherence with field data, though QUAL2K showed slightly better results as it is able to simulate the conversion of algal death to BOD, fixed plant DO and denitrification (Park & Lee, 2002). The study on the Bagmati River on the other hand showed that QUAL2K gave good representations of the field data especially in DO and BOD simulations (Kannel et al., 2007).

4.0 Methodology

4.1 Sampling Site

Sg Serin serves as a source of water for residential and commercial use for the nearby community in Serian (Ling et al., 2006). The river was sampled at seven locations off the old Kuching-Serian Road where four stations were located on Sg Serin itself while the remaining three stations were located on its tributaries (Figures 1 and 2). The tributaries sampled include Sg Penat, Sg Bukah and Sg Pam as these streams contribute significantly to the inflow and water quality of Sg Serin. The coordinates and descriptions of the sampling stations are further summarized in Table 1. At each station, both hydrogeometric data and water quality data were measured.

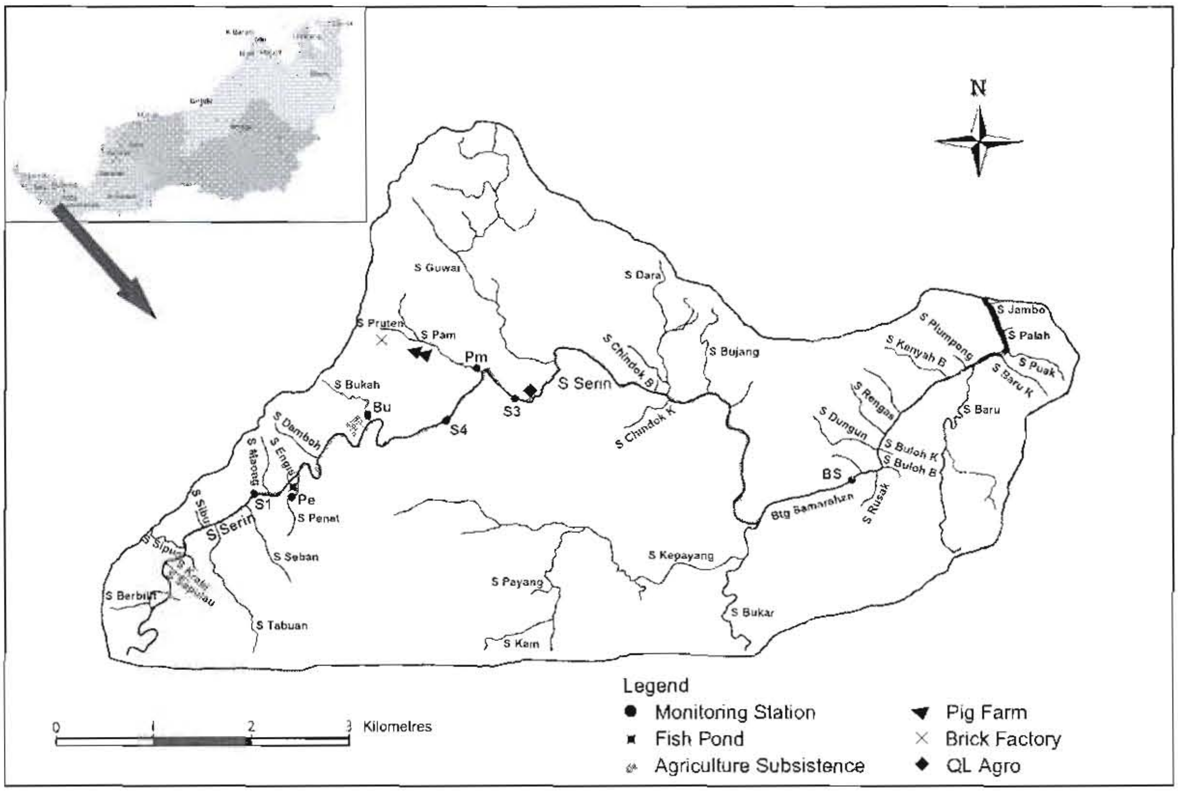

Figure 1 Point Sources and monitoring stations are shown on the Sg Serin basin

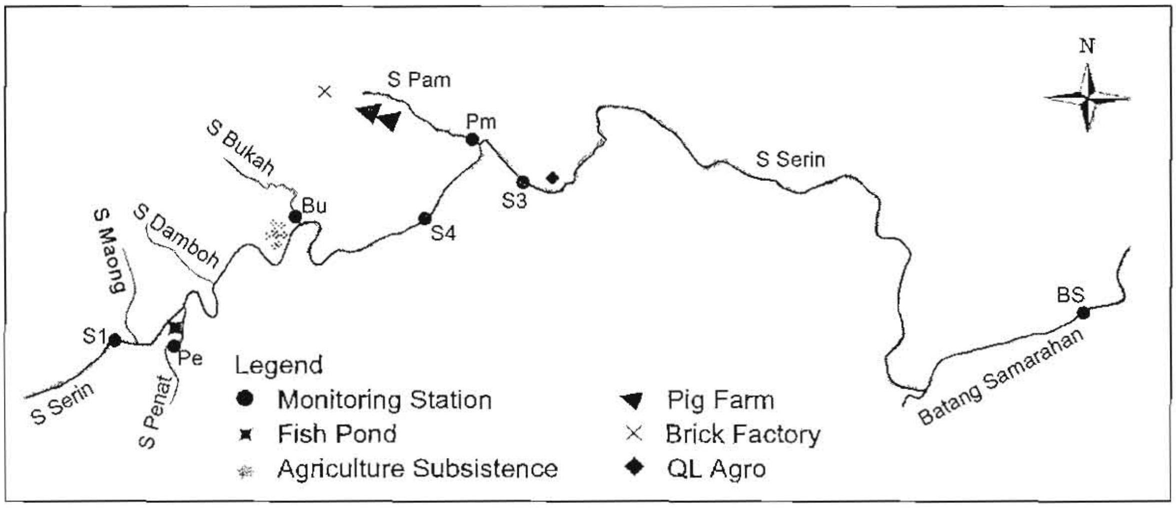

Figure 2 The stretch of river used for water quality monitoring and modeling

Table 1 Summary of the seven sampling stations describing the activities nearby the stations as well as its coordinates and locations.

Station	Description	Location[a] (KM)	Coordinates
S1	Headwater; located near a school in Kg Ma'ang	10.00	N 01°15'54.0" E 110°24'48.1"
Pe	Tributary; stream is blocked to sustain a fish pond	9.45	N 01°15'49.4" E 110°24'58.2"
Bu	Tributary; situated near patches of agricultural land	8.10	N 01°16'17.8" E 110°25'25.9"
S4	Main river; located near a bridge at the old Kuching-Serian road	6.75	N 01°16'22.5" E 110°25'51.7"
Pm	Tributary, receives animal farm effluent	6.20	N 01°16'32.6" E 110°25'57.3"
S3	Main river; dump site for nearby agricultural factory, QL Agro	5.65	N 01°16'20.0" E 110°26'13.7"
BS	Main river; located near the bridge at the new Kuching-Serian highway. Continues to flow to Batang Samarahan	0.00	N 01°15'55.4" E 110°28'01.2"

[a] Locations are determined using BS as the reference point.

4.2 Field Sampling

Field sampling was conducted from January to March 2009 where the dates were further divided for calibration and validation data. For calibration data, all stations were sampled for hydraulic data and water quality on 4 and 17 January, 19 February and 13 March 2009. For the validation data, only the main river was sampled for both hydraulic and water quality data on 10 January and 6 February 2009. The sampling dates are summarized in Table 2.

Table 2 Summary of sampling dates from January to March 2009

Calibration		Validation	
4-Jan-09	All stations	10-Jan-09	S3, S4, BS
17-Jan-09	All stations	6-Feb-09	S3, S4, BS
19-Feb-09	S3, S4, BS		
13-Mar-09	S1, Pe, Bu, Pm		

4.2.1 Hydraulic Data

Both the coordinates and elevation of each station was determined with a GPS and the velocity of the river at each station was measured with a portable flow meter (Marsh-McBirney Model 2000 Flo-Mate). The depth of the river at each station was measured with a depth finder (Hondex PS-7 LCD Digital Sounder) while the width of the river was determined using a range finder (Bushnell Elite 1500). The length of the river was determined from the first station to the last station from a 1: 50000 topography map and cross referenced with GoogleEarth. The river is assumed to be trapezoidal and the cross section of the river was divided into two segments in order to calculate the cross sectional area. The flow of the river was then determined with the equation:

$$Q = A_c \times U \quad (1)$$

where Q is flow (m^3/s), A_c is cross sectional area (m^2) and U is velocity (m/s).

4.2.2 Water Quality Sampling

Temperature, pH and DO were measured in situ from 9 a.m. to 12 p.m. using the YSI 6600 multiparameter water quality monitor. Grab samples were collected for BOD_5, inorganic phosphorus (P_{io}), organic phosphorus (P_o) and heavy metals (Ni, Zn and Pb). Water samples for phosphorus analysis were collected in 2L polyethylene bottles before being stored at 4°C in a cooler for further analysis in the laboratory. For BOD_5, water samples were collected in standard 300 ml BOD bottles and consequently kept in a cooler for four hours before being analyzed in the lab (APHA, 1998; United Nations Environment Programme, World Health Organization, 1996). Water sample for heavy metal analysis were collected in 1L glass bottles and preserved immediately in situ with HNO_3 until the pH is less than 2.

4.3 Laboratory Analysis

The initial DO for BOD_5 was immediately analyzed upon the samples' arrival in the lab according to procedures as outlined in the Standard Methods for the Examination of Water and Wastewater, 20th edition. The holding time was kept within 4 hours prior to analysis due to the travel distance from the sampling site to the laboratory. Samples from tributaries were diluted with aerated distilled water before the initial DO measurement was taken while samples from the main river were not diluted as they did not require dilution. The initial DO was measured in the laboratory with a DO meter (YSI 5500) after which the samples were incubated in the dark at 20°C for 5 days. After 5 days, the final DO level was measured again with the DO meter (YSI 5500) to determine the BOD_5

P_{io} was analyzed using the Hach DR/2010 portable spectrophotometer according to the PhosVer3 (Ascorbic Acid) method (Hach, 2000). PhosVer3 Phosphate Powder Pillows were reacted with 10 ml samples for 2 minutes to test for orthophosphates. The orthophosphates react with ammonium molybdate and potassium antimonyl tartrate to form phosphomolybdic acid which is reduced by ascorbic acid to a molybdenum blue colour. The blue colour is then detected by the spectrophotometer at 890 nm (APHA, 1998; Hach, 2000).

P_o was measured by subtracting P_{io} from TP. For TP analysis, 10 ml samples were digested with concentrated nitric acid and concentrated sulfuric acid as outlined in the nitric acid-sulfuric acid digestion method (APHA, 1998). Digestion was necessary to oxidize organic matter and release organically-bound phosphorus as orthophosphates (APHA, 1998). The digested samples were then neutralized with sodium hydroxide and diluted to 100 ml before TP was determined using the PhosVer3 (Ascorbic Acid) method (Hach, 2000).

The samples for heavy metal analysis were filtered with 45mm diameter, 1.2 μm pore size microfibre filter paper (Whatman GF/C) before being diluted with ultra pure water. HNO_3 (1%) was added into the diluted samples and the samples were then analyzed with ICP-MS for Ni, Zn and Pb. Standards were prepared using 0 – 5 ppb solutions.

4.4 Statistical Analysis

All statistical analysis was conducted using SPSS version 12 where two-way analysis of variance (ANOVA) was conducted on the field results to determine the significance of station and date on the measured parameters. Pairwise comparisons amongst stations and dates were also conducted to test the significant difference between the stations and dates themselves.

4.5 River classification

Sg Serin was further classified according to the Interim National Water Quality Standards for Malaysia to gauge the quality of the river.

4.6 Model Calibration and Validation

4.6.1. Calibration

4.6.1.1 River Segmentation

Sg Serin was divided into 16 reaches based on hydrogeometry similarities between the reaches. The first reach that is the headwater, started from S1 while the last reach ended at BS. The reach lengths ranged from 0.2 to 2.05 km and its location was determined using BS as the reference point (Table 1). The tributaries of Sg Serin were added as point sources at the location at which it joins the main river. The segmentation is shown in Figure 3.